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Prototype Superconducting Triple-Spoke Cavity for Beta = 0.63*

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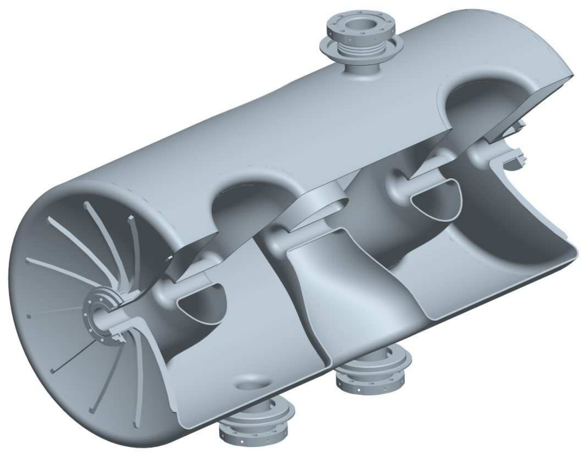

Figure 1: Cut-away view of the 46.6 cm diameter niobium shell of the $\beta \cong 0.63$ triple-spoke cavity

Abstract

This paper reports the development status of a 345 MHz, three-spoke-loaded, TEM-class superconducting cavity with a transit-time factor peaked at $\beta = v/c = 0.63$. The cavity has a 4 cm diameter beam aperture, a transverse diameter of 45.8 cm, and an interior length of 85 cm. The cavity is the second of two three-spoke loaded cavities being developed for the RIA driver linac and other high-intensity ion linac applications. Construction of a prototype niobium cavity has been completed and the cavity has been chemically processed. Results of initial cold tests are discussed.

INTRODUCTION

This paper is one of two papers presented at this conference reporting the status of triple-spoke cavities being developed for the high-energy section of the driver linac for the proposed U. S. rare-isotope accelerator facility (RIA) and other ion-linac applications [1,2]. The aim of the work presented in both papers is to demonstrate the feasibility of using spoke cavities for the high energy section of the RIA driver linac by cold-testing prototype niobium three-spoke-loaded cavities.

For more details of the cavity design and construction, see reference [3], which is presented at this conference, describing a similar three-spoke-loaded niobium cavity.

In what follows we discuss the design, processing, and test results for a 345 MHz, three-spoke-loaded superconducting cavity for particle velocities $\beta \cong 0.63$.

Frequency	**345 MHz**
$\boldsymbol{\beta_0}$	**0.63**
L($3\beta\lambda/2$)	**82 cm**
QR_S (G)	**93 Ω**
R/Q	**549 Ω**
below for E_{ACC} = 1.0 MV/m	
RF Energy	**0.565 J**
$\boldsymbol{B_{PEAK}}$	**90 G**
$\boldsymbol{E_{PEAK}}$	**2.93 MV/m**

Table I: Electromagnetic properties of the cavity

CAVITY DESIGN

Figure 1 shows a sectioned view of the niobium shell of the three-spoke-loaded cavity. The OD of the shell is 46.6 cm and the overall length of 101.6 cm. A 2-inch diameter coupling port can be seen at the top of the cavity: external niobium support ribs surrounding the beam port are visible at the end of the cavity.

The design was constrained to provide a 345 MHz three-spoke-loaded cavity of $\beta_0 = 0.63$ with a 4 cm beam aperture. The design priorities were to minimize the peak surface electric and magnetic fields and to provide good mechanical stability.

The spoke elements are elliptical in cross section in order to minimize the peak surface fields while accommodating a 4 cm beam aperture. The major axis of the ellipse is normal to the beam axis in the center of each

Figure 2: Three major subassemblies of the beta=0.62 triple-spoke resonator after final electropolishing

spoke to minimize the surface electric field and maximize the beam aperture. The major axis is parallel to the beam axis in the region of the spokes near the outer cylindrical diameter of the cavity in order to minimize the peak surface magnetic field.

The three lowest frequency rf eigenmodes of the cavity are TEM-like modes with each spoke excited as a half-wave line. The accelerating rf eigenmode is the lowest frequency mode, in which adjacent spokes differ in phase by π radians.

Table I details the electromagnetic properties for accelerating rf eigenmode. The accelerating gradient E_{ACC} in Table I is referenced to an effective length l_{eff} = $3 \cdot \beta_0 \cdot \lambda/2$ = 82 cm.

SURFACE PROCESSING

Electropolishing

In order to remove damage to the niobium surface due to forming and machining and to provide a smooth and brilliant rf surface the cavity was heavily electropolished (EP). EP was performed separately on the three major subassemblies of the spoke cavity: the cylindrical housing complete with three spoke elements, and the two spherical end wall sections, all shown in Figure 2.

The housing was electropolished with the beam axis oriented vertically. In order to give a more even surface removal, the housing was flipped over midway through the procedure. The end-wall assemblies were electro-polished with the rf surface facing upward.

The total thickness removed from the surface of the spokes and the spherical end wall sections was measured with an ultrasonic thickness gauge, and ranged from 150 to 200 microns. A somewhat lesser amount, about 115 microns, was removed from the cavity housing.

After electron beam welding of the cavity end walls to the housing the niobium cavity was filled with standard 1:1:2 BCP for a total of 7 minutes at 12^{o}C to remove any residue or oxide buildup from electron-beam welding.

High-pressure rinsing

Following BCP, the cavity was rinsed with filtered 18 MΩ-cm, high-pressure water at a rate of 20 liters per minute for roughly one hour through each of the beam ports. Rinsing was performed with the beam axis oriented horizontally, and the water drained out though the 2 inch diameter radial coupling ports.

The cavity was rotated 180^{o} about the beam axis several times during rinsing to minimize pooling of particulates in the housing. Drying was performed in a curtained clean room area for 24 hours before the cavity ports were sealed with standard stainless-steel vacuum flanges sealed with copper gaskets.

Following the initial cold tests, the cavity surface was processed a second time in an effort to improve cavity performance. Buffered chemical polishing was performed for 4 minutes at 13^{o}C followed by high-pressure rinsing. In this second round, to maximize coverage, rinsing was performed for about 45 minutes separately through each of the five coupling and beam ports.

Clean room assembly

Assembly of the rinsed cavity together with high-pressure-water-rinsed variable power coupler and cavity vacuum system hardware was performed in a clean assembly area. The clean assembly was performed with cavity installed inside the cylindrical test-cryostat vacuum shell. The rf coupler and cavity-vacuum pumping line were inserted though an access flange on the bottom wall of the cryostat and attached to the cavity using standard copper-gasket vacuum flanging. Particulate levels were monitored throughout the assembly procedure using a hand-held laser particle counter, and were consistent with class 100 to class 1000 conditions.

COLD TESTS

Cavity Cool-down

The cavity and associated helium reservoir were cooled rapidly by using liquid helium from an external 500 liter He storage dewar. The cooling rate through the temperature range 75 K - 150 K, generally accepted as the hydride formation region for high RRR niobium, was about 40 K per hour. A somewhat faster cooling rate of 80 K per hour was achieved in a subsequent cool-down by removing restrictions to the helium flow as far as was feasible. The effect of cool down rate on cavity performance is discussed in the following sections.

Superconducting Performance

After cooling the cavity to 4 K, the cavity test cryostat was attached to the helium refrigeration system of the ATLAS accelerator. CW conditioning of low- and medium-field multipacting, was performed for three hours with up to 200 Watts of rf. This was followed by roughly 1 hour of short-pulse conditioning with the maximum rf power available, 1.3 kW, with the cavity at 4.5 K.

Although some x-ray emission was observed at accelerating field levels of 8 MV/m and above, the test results shown in Figure 3 indicate that field emission was not a major source of rf loss in operation at 4 K.

Measurements at 2K were performed by disconnecting the test cryostat from the ATLAS refrigerator, venting to atmosphere and then cooling to 2 K by pumping the helium vapor with a Roots blower.

Figure 3 shows the best performance obtained at 4.2 K and at 2 K. We note that performance exceeded the nominal RIA design operating gradient of 9.4 MV/m. The highest gradient reached at 4.2 K, E_{ACC}=10.6 MV/m, was limited by the 270 Watts of rf power available at the time of the measurement. In earlier measurements at T=4.2 K, the cavity quenched at E_{ACC}=11.5 MV/m with a cw input power of 398 Watts.

Hydrogen Q-disease

The data in Figure 2 show a greater increase of rf loss with increasing field level, so-called Q-slope, than we have observed for the other four types of cavity prototyped at ANL for the RIA driver [4-6]. We tested the possibility that hydrogen Q-disease may be contributing to the rf loss by warming the cavity and holding it for 48 hours in the temperature range 110 K – 140 K. On then cooling the cavity to helium temperature, we found the cavity Q was severely degraded, by a factor of 10 to 100.

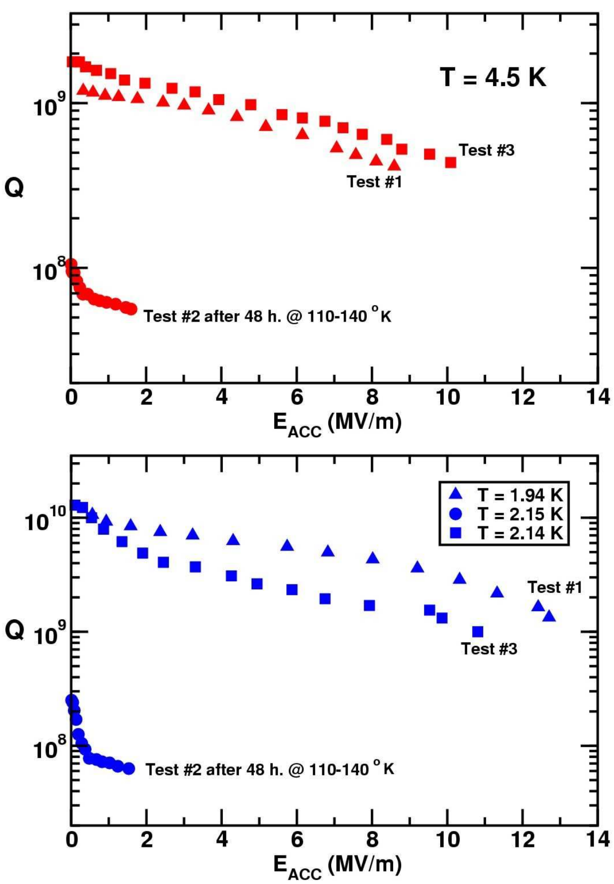

Figure 4: Cavity Q *vs.*E_{ACC} at 4.5 K (top) and 2 K (bottom) for a sequence of tests described in the text.

Following this test (Test 2), the cavity was thermally cycled to 310K and cooled as rapidly as possible to 4K. The performance not only recovered, but was slightly improved by the faster cool-down (Test 3). The results of all three sets of measurements are summarized in Figure 4, with measurements at 4.5 K shown at the top, and at 2K shown at the bottom.

In Figure 4, the data labeled 'Test 1' were from the initial test in which the cavity was cooled from 150K to 75K in 105 minutes. Test 2 followed a 48 hour hold in the temperature region 110-140K. Test 3 was performed after cycling the cavity to 310K, and then cooling from 150K to 75K in only 55 minutes.

The results shown in Figure 4 are consistent with hydrogen contamination as has been observed for cavities in this frequency range [7] and above. It has generally been thought that the molecular hydrogen evolved during electropolishing could load the niobium with hydrogen. However, it has also been suggested that electron beam welding may be a primary cause of hydrogen uptake [8].

Whatever the mechanism, the data suggest that present performance is limited by hydrogen. This being the case, baking the cavity at 600-800 C, which is known to remove hydrogen from high RRR niobium, is likely to further reduce rf losses and improve performance.

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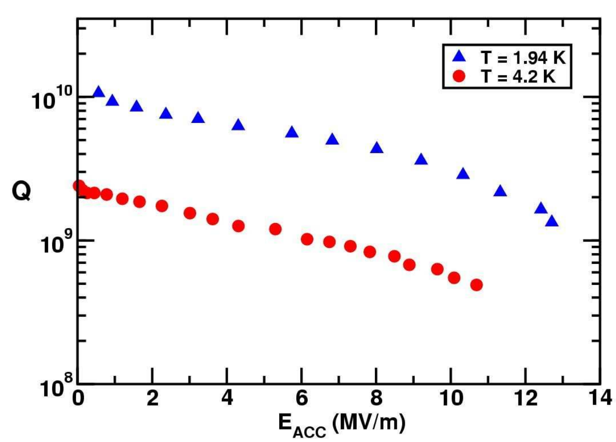

Figure 3: Cavity Q as a function of accelerating gradient

W-31_109_ENG_38.

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